BIOLOGICAL CONTROL

Seasonal and Diurnal Dynamics of Beneficial Insect Populations in Apple Orchards Under Different Management Intensity

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ABSTRACT Limb jarring samples were taken in four experimental apple orchards (one completely unmanaged; one with horticultural management and no pest management; one with horticultural management, no pest management, and interplanted with peach and sour cherry; and one under conventional commercial management practices) at hourly intervals over a 24-h period at four times in 1991. A total of 1,176 individual predators belonging to seven orders and 22 families was collected. The most abundant species was *Coniopteryx* sp. (Coniopteryigidae: Neuroptera), and the most abundant family was Coccinellidae (Coleoptera). A total of 396 adult parasitoids was collected from 26 families of Hymenoptera and one Diptera family, with Encyrtidae being the most abundant. All other individuals were classified as potential food items and were identified only to order or, in some instances, family. A total of 5,812 potential food items was collected. Diversity of predators and parasitoids was greatest in May and June. Diversity of predators was highest on apple trees that were inter-planted with peach and cherry trees, whereas parasitoid diversity was greatest on peach trees and on insecticide treated apple trees. Chrysopids (Neuroptera), clerids (Coleoptera), and *Leptothrips mali* (Fitch) (Phlaeothripidae: Thysanoptera) were most commonly collected at dawn or during the night, suggesting that their role in orchards may be underestimated by sampling only during daylight hours. With the exception of Scelionidae and Platygastridae (Hymenoptera), parasitoids were most commonly collected during the night. Results indicate that peach trees are attractive to both predators and parasitoids and therefore may be a valuable addition to apple orchards to enhance the abundance of biological control species.

KEY WORDS apple, diel periodicity, biological control, orchard management, biodiversity

NUMEROUS THEORIES HAVE been proposed to explain differences in animal diversity (Price 1997), many of which are applicable to the spatial scale of arthropod diversity in individual orchards within the same geographical region. Increasing orchard age can affect arthropod diversity by increasing plant structural diversity (Lawton and Schröder 1977, Lawton 1983, Leather 1986), increasing the diversity of the plant community associated with the orchard (Whittaker and Woodell 1969, Fowler and Lawton 1982), and increasing successional stage (Southwood et al. 1979). Size of the orchard, closeness to a potential species pool for immigration, and orchard age together can affect arthropod diversity through mechanisms pertaining to island biogeography theory (MacArthur and Wilson 1963). Orchard management practices also have an important effect on the arthropod community in apples (Liss et al. 1986, Brown and Welker 1992, Rieux et al. 1999, Suckling et al. 1999). Frequency and severity of disturbances in a community impact the diversity of the community (Loucks 1970). Szentkirály and Kozár (1991) compared the resource diversity hypothesis (Price 1997) and intermediate disturbance hypothesis (Petraitis et al. 1989) to explain differences in the number of species in various Hungarian apple orchards. They (Szentkirály and Kozár 1991) found that the diversity of surrounding habitat (resource diversity hypothesis) was the stronger determinant of diversity within the orchard, but intensity of disturbance was also important. Brown and Adler (1989) found that disturbance history was the important determinant of community diversity in northeastern U.S. apple orchards.

One objective of this study was to describe arthropod diversity in apple orchards under different intensities of orchard management, with special emphasis on populations of potential biological control species. Diversifying agroecosystems is a way to increase diversity of the arthropods in the system and to increase biological control (Pimentel 1961, Risch et al. 1983). For instance, the addition of flowering ground cover plants to the orchard ecosystem has been shown to increase biological control of orchard pests (Wyss 1995, Brown et al. 1997, Jenser et al. 1999). In this study, we examined the effect of interplanting tree species within the orchard rather than using ground cover plants. A second objective of the study was to examine the diel periodicity of beneficial insect populations in the orchard and seasonal changes in the beneficial community.

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Table 1. Hypotheses of expected responses in diversity to different characteristics in orchard management and orchard structure

Orchard	Tree architecture	Tree age, yr	Understory plant diversity	Tree diversity	Insecticide use	Expected beneficial insect diversity
A	Complex	8	High	Low	No	Highest
C	Complex	8	Low	Low	No	High
D	Moderate	3	Low	High	No	Moderate
M	Complex	13	Low	Low	Yes	Low

Orchard A, unmanaged; Orchard C, horticulture management only; Orchard D, horticultural management only and interplanted apple, peach and cherry; and Orchard M, complete horticultural and pest management.

Materials and Methods

Four orchards at the Appalachian Fruit Research Station, Kearneysville, WV, were sampled four times during 1991. Orchard A (0.32 ha) was 8 yr old and had been completely unmanaged for 6 yr. This orchard had no pesticides applied and had not been mowed since 1985. It had high plant diversity with natural recruitment of other trees, vines, and herbaceous plants intermixed with the apple trees. Orchard C (0.13 ha) was also 8 yr old but was regularly mowed, pruned and had the herbicide paraquat applied in the tree rows as the only pesticide. Within orchards A and C there were equal numbers of the apple cultivars 'Delicious', 'Golden Delicious', 'Empire', 'York Imperial', and 'Stayman'. Orchard D (0.22 ha) was 3 yr old and had the same horticultural management and pesticide use as orchard C. Orchard D had the apple cultivars 'Prima' (29 trees) and 'Liberty' (27 trees), peach cultivars 'Summerglo' (29 trees) and 'Harmony' (27 trees), and sour cherry cultivar 'Montmorency' (14 trees). Within rows, apple and peach trees were planted alternately. Cultivars were alternated between rows. The cherry trees were planted randomly throughout the orchard, in place of peach trees. The only pest managment activity used in orchard D was mating disruption for lesser peachtree borer, *Synanthedon pictipes* (Grote & Robinson), with one pheromone dispenser applied per tree on one June for mating disruption. Orchard M (0.45 ha) was 13 yr old and was managed with conventional orchard production practices. This orchard contained only the cultivar 'Granny Smith'. Insecticide applications consisted of dormant oil on 25 March; chlorpyrphos on 6 April, 5 June, and 8 August; methomyl with azinphos-methyl on 8 May; formetanate hydrochloride on 20 June; methyl parathion on 10 July; and methyl parathion with propargite on 24 July. Except for orchard A, all orchards had a herbicide strip under the trees maintained with paraquat as needed throughout the season.

Sampling was done at hourly intervals over a continuous 24-h period at four times during the year. Sampling was within 5 d of a full moon on days when the forecast was for clear skies to reduce the need for artificial light during nocturnal sampling. Sample periods for orchards A, C, and D were 29–30 May, 25–26 June, 31 July–1 August, and 26–27 August (full moons in 1991 were on 28 May, 26 June, 26 July, and 25 August). Sampling began at 0900 hours and continued to 0800 hours EDT the following day. Every hour, two apple trees in orchard A, two apple trees in orchard C, two apple and two peach trees in orchard D were sampled. Every other hour, one cherry tree was also sampled in orchard D. In the first sample period, 2 h of sampling (2400 and 0300 hours) were missed due to the length of time required to obtain samples during the night (the cherry tree selected for sampling at 0300 hours was sampled on time). An additional apple tree was not sampled in orchard D at 2200 in the May sample. Trees were randomly selected before beginning the sample period, and no tree was sampled twice during one sample period. Due to time limitations and distance between orchards, sampling in orchard M was done on 31 May–1 June, 24–25 June, 27–28 July, and 24–25 August. Sample frequency was also less in orchard M, with 10 trees sampled at 1300 hours and 2000 hours on the first day and at 0100 hours the following day. As with the other orchards, the trees were randomly selected before going to the field, and no tree was sampled twice during the same sample period.

Sampling was by limb jarring, with three branches per tree struck three times with a rubber hose over a collection funnel. The funnel was made of clear plastic and had a 1-m^2 collection opening. The funnel was held with a handle from a sweep net that allowed one person to hold the funnel while striking the branch. A 200-ml jar containing 50–100 ml 70% alcohol was attached to the bottom of the funnel. The sample with all specimens from the three branches per tree was carried to a central location where the jar was unscrewed from the funnel, covered, labeled, and replaced with a new sample jar. Before the jar was removed from the funnel, all arthropods on the inside surface of the funnel were dislodged into the collecting jar. Leaves and fruit that fell into the funnel were removed after rinsing arthropods that were on the plant material into the jar. Samples were taken to the laboratory for specimen identification. Spiders and ants were omitted from this analysis and will be treated separately in subsequent papers. Phytophagous arthropods and parasitic Hymenoptera were identified to family. Predatory arthropods were identified to species as well as possible, with identifications and verifications provided by the Systematic Entomology Laboratory, USDA-ARS, Beltsville, MD. Representative specimens from identified species are in the arthropod collection at the Appalachian Fruit Research Station, Kearneysville, WV.

Data were grouped into three trophic groups of arthropods for analysis: predators, parasitoids, and potential food resources. Specific hypotheses regarding the relative diversity in each orchard with supporting justification are presented in Table 1. Linear correlations were calculated between the number of individual food items and natural enemies, and also between the diversity of these trophic groups (SAS Institute 1985). Diversity was estimated with Shannon's index of diversity using the formulae of Hutcheson (1970), which also provided an estimate of the variance of the diversity estimate for statistical comparison using 95% confidence intervals. A two factor analysis of variance (ANOVA) (SAS Institute 1985) was used to test the significance of month and orchard for the predator and parasitoid trophic groups. The interaction between orchard and month was not testable because there was no replication of orchards within month. Diel periodicity was tested for all taxa with >20 individuals using the Rayleigh test (Batschelet 1981), a circular statistic to test for randomness in the distribution of angular data with a potential distribution of 360°. In this case, hour (0–2400 hours) was transformed into radians for the analysis. Data from orchard M was not included in the diel analysis because only three time intervals were sampled.

Results

Predators. A list of all predaceous insects collected in each orchard is presented in Table 2. The undetermined specimens listed were almost exclusively immature forms that could only be identified to family level. In total 1,176 predators, belonging to seven orders and 22 families, were collected. Coccinellidae (Coleoptera) was the most abundant family, with the most individuals (283) and the most species (16). The most abundant species, however, was *Coniopteryx* sp. (Coniopterygidae: Neuroptera), with nearly as many individuals (271) as there were coccinellids. Three families of omnivores [Gryllidae (Orthoptera), Forficulidae (Dermaptera), and Miridae (Hemiptera)], included in the list of predators, comprised 18.94% of the total predators. The number of predators per tree ranged from 0.93 on apple in orchard D to 1.58 in the conventionally managed orchard, M (Table 2).

Parasitoids. The number of adult parasitoids by orchard and tree species is shown in Table 3. A total of 396 parasitoids, belonging to 26 families of Hymenoptera and one family of Diptera, was collected. Encyrtidae, Eulophidae, and Platygastridae were the most abundant families, comprising 17, 13, and 12% of all parasitoids, respectively. Abundance per tree sampled was highest for cherry (0.56) and lowest for apple in orchard D (0.27). In subsequent analyses, only those families with >30 individuals were analyzed separately (Eulophidae, Encyrtidae, Eucoilidae, Scelionidae, and Platygastridae), whereas all others were pooled.

Potential Food Resources. A total of 5,812 individuals considered as potential food resources for the predators and parasitoids was collected in all four orchards over the season. These potential food resources were identified to order, and in some cases to a few of the more abundant families, and are listed in Table 4. Numerically, >80% of the potential food resources collected were Acari, Homoptera, and Coleoptera. The number of individuals per tree sampled was between 6.28 and 6.98 except on apple in orchard D (5.76) and in orchard M (5.40). The number of potential food individuals per orchard was significantly correlated with both the number of predators ($r = 0.90$, df = 4, $P < 0.05$) and the number of parasitoids ($r = 0.91$, df = 4, $P < 0.05$).

Community Dynamics. Predator diversity was greatest in May and June and lowest in August (Table 5). Diversity of predators was significantly highest on apple in orchard D and significantly lowest on cherry in orchard D (largely due to the smaller sample size for cherry) (Table 6). Predator diversity on peach in orchard D, the conventionally managed apple in orchard M, and the unmanaged orchard A was significantly lower than in the unsprayed but horticulturally treated apple trees in orchards C and D. Diversity of parasitoids was greatest in June (Table 5) and also on peach in orchard D and in orchard M (Table 6). Both cherry and apple in orchard D had a low diversity of parasitoids. Diversity of the food resources was significantly different between all months (Table 5), being highest in May and lowest in July. Diversity of food resources was lowest in orchard M and consistently higher in all the other apple orchards and on peach in orchard D.

The diversity of predators was significantly correlated with the number of potential food individuals ($r = 0.97$, df = 2, $P < 0.05$). The diversity of the potential food resources was not correlated with either number or diversity of predators or parasitoids.

The ANOVA (Table 7) showed month to be significant for Thysanoptera (all families pooled), Anthocoridae, Miridae, Coniopterygidae, Hemerobiidae, Cantharidae, and *Hyperaspis proba* (Coccinellidae: Coleoptera). Thrips, anthocorids, coniopterygids, and chrysopids were all most abundant during June and July; mirids, hemerobiids, and cantharids were most abundant in May and *H. proba* was most abundant in July and August (Table 7). Orchard effect was significant only for gryllids, chrysopids, and *H. proba* (Table 7). Gryllids were significantly more abundant in orchard A, with chrysopids most common in orchard M, and *H. proba* most common on peach in orchard D. Although not significant, the acarophagous *Orius insidiosus* and *Stethorus punctum picipes* were more abundant in orchard M. Month effect was significant for all taxa of parasitoids in the analyses of variance (Table 7). Abundance was always significantly lowest in August and generally greatest in June. Encyrtidae and Platygastridae were equally abundant in May as in June, and Eucoilidae were equally abundant in July as in June. No significant differences were found among orchards for parasitoids based on the ANOVA tests.

Month was a significant factor in the ANOVA ($P < 0.05$) for all potential food items but Cercopidae. Most of the taxa were more abundant in May and June and less abundant in July and August. Homoptera (other than Aphididae, Cercopidae, and Cicadellidae) and Hemiptera, however, were least abundant in May. All Coleoptera, including Scarabaeidae, had highest

Table 2. Predatory insect species collected over all four sample periods by orchard and tree species (subtotals given for each family) in West Virginia research orchards, 1991

	Orchard					
	A	C	D Apple	D Peach	D Cherry	M
Orthoptera						
Gryllacrididae			1	1	1	
Camptonotus carolinensis (Gerstaecker)			1	1	1	
Gryllidae	65	12	26	15	3	
Neoxabea bipunctata (DeGeer)	11	2	2	4		
Oecanthus niveus (DeGeer)	5		6	2	1	
Phyllopalpus pulchellus (Uhler)				1		
Undet.	49	10	18	8	2	
Dermaptera						
Forficulidae	1	1	5	10	3	1
Forficula auricularia L.	1	1	5	10	3	1
Thysanoptera						
Aeolothripidae				1		
Aeolothrips melaleus Haliday				1		
Thripidae	1	1	1	1		1
Scolothrips pallidus (Beach)	1	1	1	1		1
Phlaeothripidae	9	20	11	12	4	13
Leptothrips mali (Fitch)	9	19	10	11	3	12
Leptothrips sp.		1	1	1	1	1
Hemiptera						
Anthocoridae	9	21	8	10		30
Orius insidiosus (Say)	9	21	8	9		30
Cardiastethus sp.				1		
Miridae	21	17	14	10	3	16
Plagiognathus politus Uhler		3	1	2		3
Lopedia media (Say)	1					1
Hyaliodes vitripennis (Say)		1	2		1	3
Deraeocoris nebulosus (Uhler)						1
Ceratocapsus pumilus (Uhler)	6	2		3		
Phytocoris antennalis Reuter	2					
P. mundus Reuter						1
Phytocoris sp.		5	1	1		
Halticus bractatus (Say)	1			1		
Undet.	11	6	10	3	2	7
Nabidae	4	2	2		1	4
Nabis americoferus Carayon	1		1			1
N. roseipennis Reuter		1				3
N. rufusculus Reuter	1					
Nabis sp.			1			
Lasiomerus constrictus (Champion)		1				
Undet.	2				1	
Reduviidae	2	1		2		
Arilus cristatus (L.)				1		
Rocconota annumlicornis (Stål)	1					
Zelus sp.	1					
Undet.		1		1		
Phymatidae			1			
Phymata pennsylvanica Handlirsch			1			
Lygaeidae		1		1		5
Geocoris bullatus (Say)						1
G. punctipes (Say)						4
Geocoris sp.		1		1		
Pentatomidae	2	1		1		
Podisus maculiventris (Say)	1	1		1		
P. placidus Uhler	1					
Neuroptera						
Coniopterygidae	64	73	47	64	14	9
Coniopteryx sp.	64	73	47	64	14	9
Hemerobiidae	4	6	2	5		4
Hemerobius sp.	1	2		2		
Micromus sp.		2		2		3
Undet.	3	2	2	1		1
Chrysopidae	8	10	7	11	2	36
Chrysopa plorabunda Fitch				1		
C. oculata Say	3	2	1			8
C. rufilabris (Burm.)	3	3		8		9
Chrysopa sp.		3				
Undet.	2	2	6	2	2	19

Table 2. Continued.

	Orchard					
	A	C	D			M
			Apple	Peach	Cherry	
Coleoptera						
Carabidae	1	1	1	1	1	
Lebia viridis Say	1	1		1		
Undet.			1		1	
Cantharidae	10	19	11	12	3	10
Podabrus rugulosus LeConte	7	15	8	8	2	5
C. marginatus F.	3	2	2	2		5
Cantharis sp.		2	1	2	1	
Cleridae	11	2	4	5	2	
Enoclerus rosmarus (Say)	1		1			
E. ichneumoneus (F.)				1		
Phyllobaenus unifasciatus (Say)	4	2	1		1	
P. humeralis (Say)	6		1	4	1	
Phlogistosternus dislocatus (Say)			1			
Coccinellidae	42	56	30	83	17	55
Adalia bipunctata (L.)				1		
Chilocorus stigma (Say)	1	2	1	1	1	2
C. septempunctata L.	1	9	14	2	1	11
Cycloneda munda (Say)				1		1
C. maculata lengi Timberlake					1	
Olla v-nigrum (Mulsant)			1	1		
Scymnus circumspectus Horn	4	5			1	
S. iowensis Casey		1	1	2	3	
S. caudalis LeConte				1		
Scymnus sp.				5	1	
Stethorus punctum picipes Casey	16	22	6	24	3	39
Zilus horni Gordon	4	1				
Hyperaspis proba (Say)	8	9	6	41	4	
Diomus terminatus (Say)	1	1		2	1	
Psyllobora vigintimaculata (Say)	1				1	
Microweisea misella (LeConte)	2	3	1	1		
Immatures	1	3				2
Undet.	3			1		
Diptera						
Cecidomyiidae	2	6	2	3		2
Aphidoletes aphidimyza (Rondani)	2	1		2		
Lestodiplosis spp.		5	2	1		2
Asilidae		1				
Undet.		1				
Syrphidae		2	1	1		4
Sphaerophoria sp.						1
Eristalis arbustorum L.						1
Eristalis sp.		1				
Undet.		1	1	1		2
Total no. individuals	256	253	174	249	54	190
No. trees sampled	188	188	187	188	48	120
Individuals per tree	1.36	1.35	0.93	1.32	1.12	1.58

abundance in June and July. Abundance of Trombidiidae was bimodal with higher abundance in May and July. Tetranychidae and Aphididae were significantly more abundant in orchard M, and Trombidiidae and Homoptera other than Aphididae, Cicadellidae and Cercopidae were significantly less abundant in orchard M. Coleoptera were significantly more abundant on peach and cherry trees in orchard D, and Lepidoptera were most abundant in orchards A, C, and on apple in D than on peach and cherry trees in orchard D or in orchard M.

Diel periodicity. Most taxa of predators were collected randomly with regard to time of day (Table 8). Chrysopids had a significant peak of occurrence near dawn, at 0620 hours. Clerids and *Leptothrips mali* (Phlaeothripidae: Thysanoptera) had significant peaks of occurrence during the night, at 2300 and 0200 hours, respectively. Gryllids were more abundant in the early morning, at 0440, but with a significance of $P = 0.06$. Scelionidae and Platygastridae were collected at random with regard to time of day (Table 8). All other taxa of parasitoids, including the pooled abundance of the less common families, were significantly more abundant in the early morning hours, 0120 to 0340 hours.

Discussion

Our results document a large and diverse community of natural enemies in West Virginia fruit orchards (Tables 2 and 3). Sampling was only by limb jarring, and therefore underestimated the biodiversity of the

Table 3. Total number of parasitoids by family over 4 mo by orchard and tree species (subtotals given for each order) in West Virginia research orchards, 1991

	Orchard					
	A	C	D			M
			Apple	Peach	Cherry	
Hymenoptera	90	89	51	90	27	47
Braconidae	5	3	4	4	2	1
Ichneumonidae	3	2		3		1
Mymaridae	2	5	2	2	1	1
Trichogrammatidae	7	2	2	2	2	1
Eulophidae	16	8	9	10	1	7
Elasmidae				1		
Signiphoridae						1
Encyrtidae	19	17	8	13	4	7
Aphelinidae	3					
Eupelmidae						1
Perilampidae						1
Pteromalidae	5	3	1	6	1	4
Eurytomidae		1		2		
Chalcididae		1	1			
Eucoilidae	9	18	5	11	2	3
Charipidae		1		1		
Ceraphronidae	2	2	3	2		1
Megaspilidae						1
Diapriidae					1	
Scelionidae	6	6	6	10	5	9
Platygastridae	8	12	6	10	6	4
Bethylidae	1	1		4		1
Tiphiidae				1		
Vespidae				2		1
Pompilidae					1	
Sphecidae	1	3	1	2		1
Undet.	3	4	3	4	1	1
Diptera	0	0	0	0	0	2
Tachinidae						2
No. individuals	90	89	51	90	27	49
Individuals per tree	0.49	0.47	0.27	0.49	0.56	0.41

orchard by completely omitting edaphic guilds and under-sampling groups that resist dislodging (e.g., scales) or take flight (e.g., adult Lepidoptera). However, all samples were collected with the same methodology and comparisons among sample dates and orchards are appropriate. Other studies in North America have found similar numbers of species of natural enemies in apple orchards (Horsburgh and Asquith 1968, Hagley 1974, MacLellan 1977). The parasitoids collected in this study were adults and, therefore, do not give a direct indication of parasitization rates. However, the abundance of adult parasitoids foraging on fruit trees does indicate that the orchard habitat is visited by many parasitoids and suggests that parasitism rates could be expected to reflect that abundance.

Although the predatory fauna in orchards has been described in numerous other studies (Horsburgh and Asquith 1968, Hagley 1974, MacLellan 1977), the results from this study are of particular interest regarding several predator groups. The acarophagous *S. punctum picipes* was the most abundant coccinellid collected, especially in the orchard treated with insecticides. The insecticide treated orchard also had the highest number of tetranychid mites, especially when comparing individuals per tree (0.88 per tree in orchard M compared with 0.51 per tree in orchard C, the orchard with the next highest abundance of tetranychids) (Table 4). The next most abundant coccinellid was *Hyperaspis proba*, a species about which little is known. In flight traps over a Canadian agricultural landscape, *Hyperaspis bigeminata* Randall was the seventh most abundant coccinellid out of 21 species (Boiteau et al. 1999) but was found to be most abundant in June rather than later in the season, as we found for *H. proba.* Other *Hyperaspis* species are known as predators of scales and mealybugs (Homoptera) (Hodek and Honek 1996). Although scale insects are not collected by limb jarring, they were not abundant in orchard C when sampled 4 yr earlier (Kozár et al. 1994). Adult *H. proba* were most abundant on peach trees, 60% being collected on peach (Table 2). Brown and Puterka (1997) showed that there were fewer phytophagous insects found on peach trees than on apple trees. Therefore, *H. proba,* and the higher diversity of parasitoids found on peach (Table 3), were likely attracted to peach trees for some requirement other than host or prey availability. The presence of extra floral nectaries on peach leaves (Caldwell and Gerhardt 1986) could attract natural enemies to these trees as a source of energy needed for foraging. Potential food items also seem to be attracted to the secretions of the extra floral nectaries (Table 4).

Coniopteryx sp. was the single most abundant predatory insect species collected. *Coniopteryx* sp. was most abundant in the two older orchards (orchards A

Table 4. Potential arthropod food items over 4 mo by orchard and tree species (subtotals given for orders with family identification) in West Virginia research orchards, 1991

	Orchard					
	A	C	D			M
			Apple	Peach	Cherry	
Diplopoda	4	1				
Phalangida	1					
Acari	366	297	311	286	68	153
Trombidiidae	26	18	16	27	5	
Tetranychidae	75	95	81	52	14	105
Eriophyidae	50	46	48	56	9	10
Other Acari	215	138	166	151	40	38
Insecta						
Collembola	1	1	3	3	1	
Orthoptera	2	7	3		2	
Psocoptera	8	23	13	50	8	2
Thysanoptera	86	82	71	100	20	103
Hemiptera	42	35	21	28	12	26
Homoptera	407	303	286	300	81	178
Cicadellidae	239	165	171	144	37	81
Cercopidae	45	26	28	53	14	22
Aphididae	54	72	53	38	20	74
Other Homoptera	69	40	34	65	10	1
Coleoptera	294	331	274	444	117	174
Scarabaeidae	38	15	34	32	20	25
Other Coleoptera	256	316	240	412	97	149
Lepidoptera	84	96	93	53	12	11
Diptera	10	4	7	10	1	1
Hymenoptera	1					
No. individuals	1306	1180	1082	1274	322	648
Individuals per tree	6.95	6.28	5.79	6.78	6.71	5.40

and C) and on peach trees in the younger unsprayed orchard (orchard D), with only a few individuals collected from the insecticide treated orchard (orchard M) (Table 2). Dinkins et al. (1994) found *Coniopteryx westwoodi* Melander to be abundant on pecan trees in Georgia but absent in Kansas. In Florida citrus, *Coniopteryx vicina* Hagen was found to be predaceous on tetranychid and eriophyiid mites and on homopterans, especially whiteflies and scales (Muma 1967). Based on the pattern of abundance in the various orchards, *Coniopteryx* sp. were late arrivals in the succession of predatory communities on apple, being most abundant in the older orchards (orchards A and C). *Coniopteryx* sp. may also require nectar as indicated by their high abundance on peach trees. Coniopterygids are one group of insect predators that should be investigated in orchards to evaluate their potential to control mites and other arthropod pests.

An observed trend of higher numbers of several predators in orchard M, which was treated with insecticides, is of interest. The predators that preferred the conventionally managed orchard, anthocorids, *S. punctum picipes,* and chrysopids (Table 2) are important predators of tetranychid mites. Orchard M also had the highest number of tetranychid mites per tree (Table 4) and the foliage showed some mite-feeding injury (data not quantified). The predators that were abundant in orchard M have high dispersal capabilities and are able to quickly exploit new food resources such as would be available periodically in an insecticide treated orchard. It was surprising to find a high diversity of parasitoids in the insecticide treated orchard, even though the number of individuals was low (Table 3). Because the parasitoids that were collected were adults, these data suggest that parasitoids will forage in commercial orchards even if they are not permanent residents.

Table 5. Arthropod diversity (Shannon's index) for all orchards by trophic group and by month

	Pooled SEM	May	June	July	August
Predators	0.0040	2.28a	2.26a	1.86b	1.61c
Parasitoids	0.0144	2.07b	2.45a	2.16b	2.17b
Potential food	0.0005	1.73a	1.58c	1.52d	1.67b

Means followed by a different letter within a row are significantly different based on 95% confidence intervals.

Clerids, chrysopids, and *L. mali* did have significant patterns of diel periodicity (Table 8). Clerids and *L. mali* were most often collected during the dark hours (2300 hours and 0200 hours, respectively). Evaluations of the role of *L. mali* in controlling mite populations (Parella et al. 1982), therefore, may be underestimated in studies conducted only during the daylight hours. Clerids have not been mentioned as important predators on apple trees previously, and although few clerids were collected in this study, their impact, if any, has been ignored because they have been absent during daylight hours. The impact of chrysopids may also be underestimated because of their higher abundance within several hours of dawn (0620 hours) (Table 8). Most of the adult Hymenoptera were also more frequently collected during the night. (Table 8). However, this may not mean that they were more abundant

Table 6. Arthropod diversity (Shannon's Index) for all 4 mo by trophic group and by orchard

	Pooled SEM	Orchard					
		A	C	D			M
				Apple	Peach	Cherry	
Predators	0.0072	2.08c	2.14b	2.20a	2.06c	1.91d	2.07c
Parasitoids	0.0124	2.24c	2.23c	2.12d	2.46a	1.93e	2.33b
Potential food	0.0005	1.63ab	1.68a	1.64ab	1.64ab	1.61b	1.56c

Means followed by a different letter within a row are significantly different based on 95% confidence intervals.

in the dark, but rather that limb jarring is more effective at collecting these parasitoids at rest rather than during daylight when they may be foraging. Parasitoids are relatively good fliers and their response to limb jarring is expected to be flight rather than dropping when they are actively foraging.

Before conducting this study, we had a set of hypotheses regarding the patterns of diversity in the beneficial insects (Table 1). The results of our study support our initial hypotheses only with regard to potential food items (Table 6). Contrary to expectations, diversity of predators (Table 6) was highest on apple trees in orchard D. We attribute this divergence from the hypotheses (Table 1) to the presence of peach inter-planted in that orchard. We suggest that the extra floral nectaries provided food for predators directly with nectar and indirectly by attracting other potential food items that were also attracted to the nectar. The presence of a highly diverse predator and parasitoid community on the apple trees in orchard D demonstrates that although they may be attracted to nectar on the peach trees, they also spend much time foraging on apple trees for prey. The unexpectedly high diversity in the insecticide treated orchard M indicates that adult parasitoids do forage in sprayed orchards. However, parasitism rates would not be expected to be high in the insecticide treated orchards because of high mortality of both adult parasitoids and parasitized hosts.

To summarize, the insecticide treated orchard had a surprisingly large number of natural enemies. The most abundant predators in this orchard were mostly acarophagous predators that were attracted to the larger number of mites in this orchard, as is common in sprayed orchards. The large number of parasitoids indicates that these natural enemies will be able to locate prey and contribute to biological control if insecticide use can be reduced. Inter-planting the apple orchard with peach may have increased the abundance of biological control species by attracting natural enemies, apparently to the extra floral nectaries. Overall, the results from this study demonstrate the high degree of complexity of the arthropod community associated with apple. This complexity will make predicting the outcome of orchard ecosystem manipulations very difficult. In the short term, however, this study does highlight some areas of research that need to be addressed so that a more complete understanding of arthropod ecology in apple orchards can be attained to allow better ecosystem level predictions

Table 7. Results of ANOVA testing significance of orchard and month effects on abundance of major taxa of predators and parasitoids

Taxon	Orchard effect	Month effect	Summary of significant effect
Gryllidae	$P < 0.01$	NS	Most abundant in orchard A
Dermaptera	NS	NS	
Leptothrips mali	NS	$P < 0.05$	Most abundant in June and July
Orius insidiosus	NS	$P < 0.05$	Most abundant in May and June
Miridae	NS	$P < 0.01$	Most abundant in May and June
Other Hemiptera	NS	NS	
Coniopteryx sp.	NS	$P < 0.01$	Most abundant in June and July
Hemerobiidae	NS	$P < 0.05$	Most abundant in May and June
Chrysopidae	$P < 0.01$	NS	Most abundant in orchard M
Cantharidae	NS	$P < 0.01$	Most abundant in May
Cleridae	NS	NS	
C. septempunctata	$P < 0.05$	$P < 0.01$	Most abundant in June Most abundant on cherry
S. punctum picipes	NS	NS	
Hyperaspis proba	$P < 0.05$	$P < 0.05$	Most abundant in July and Aug Most abundant on peaches
Predatory Diptera	NS	NS	
Eulophidae	NS	$P < 0.01$	Most abundant in June
Encyrtidae	NS	$P < 0.05$	Most abundant in May
Eucoilidae	NS	$P < 0.05$	Most abundant in June and July
Scelionidae	NS	$P < 0.05$	Most abundant in June
Platygastridae	NS	$P < 0.01$	Most abundant in May and June
All other Hymenoptera	NS	$P < 0.01$	Most abundant in June

NS, Not significant.

Table 8. Diel periodicity for major taxa of insect predators and parasitoids (Rayleigh's test), mean peak abundance and confidence intervals presented only for taxa with significant ($P < 0.1$) periodicity in abundance

Taxon	Sample size	Probability of periodicity	Mean peak abundance, hours	95% CI (hour:min)
Gryllidae	121	0.06	0440	5:00
Dermaptera	20	0.75		
Leptothrips mali	52	<0.01	0200	4:20
Orius insidiosus	47	0.78		
Miridae	68	0.85		
Coniopteryx sp.	262	0.75		
Hemerobiidae	17	0.63		
Chrysopidae	38	0.01	0620	4:20
Cleridae	24	0.05	2300	4:20
Cantharidae	55	0.18		
C. septempunctata	27	0.20		
S. punctum picipes	73	0.26		
Hyperaspis proba	68	0.84		
Eulophidae	44	<0.01	0120	3:40
Encyrtidae	61	<0.01	0340	4:20
Eucoilidae	45	<0.01	0140	3:40
Scelionidae	33	0.45		
Platygastridae	42	0.32		
Other Hymenoptera	122	<0.01	0220	4:00

from orchard experiments. The high abundance of insectivorous gryllids, coniopterygids, and *Hyperaspis proba* in this study indicate that they could have significant impact on some groups of prey in the orchard. Studies done with chrysopids, *Leptothrips mali,* and gryllids must be evaluated in light of their greater abundance at dawn or night as was demonstrated in this study. Biological control of insect pests in orchards has much promise, but as shown in this study, there is much more basic information needed to be able to predict adequately the outcomes of any orchard ecosystem manipulation.

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